Disused Radioactive Source Silo Storage System

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Abstract

End of life management of radioactive sources is an important aspect of radiological security. Radioactive sources must be safely and securely controlled throughout their lifecycle. Disused sources are at higher risk of falling out of operational and regulatory control than sources still in use. Centralized, secure storage decreases the risk that the sources could be neglected, diverted, or lost. There is a need for additional back-end management tools to support the safe and secure disposition of radioactive sources. An optimized Silo Storage System (S3) for long-term interim storage has been developed based on many decades of silo storage technical and operational experience. Silo storage provides an economical solution that meets international standards while being modular and flexible in nature to meet the unique needs of each user country. A standard design package has been developed to support partners that are interested in collaboration.

Introduction

Disused sealed radioactive sources (DSRS) can be safely and securely stored for an interim period of over 50 years in a retrievable, below-grade Silo Storage System (S3). Vertical silo storage is a proven technology (See Figure 1) at two different facilities, each with over 50 years of experience, in the successful storage of spent nuclear fuel, highly radioactive waste, and low-level radioactive waste at the Idaho National Laboratory (INL). Carbon steel pipes with welded baseplates, which are referred to as silos or silo liners, are buried vertically in the ground such that the top of the silo protrudes above ground level by several inches. Canisters containing radioactive materials are lowered into the silo and the lid/shield plug assembly is installed to seal the silo closed.

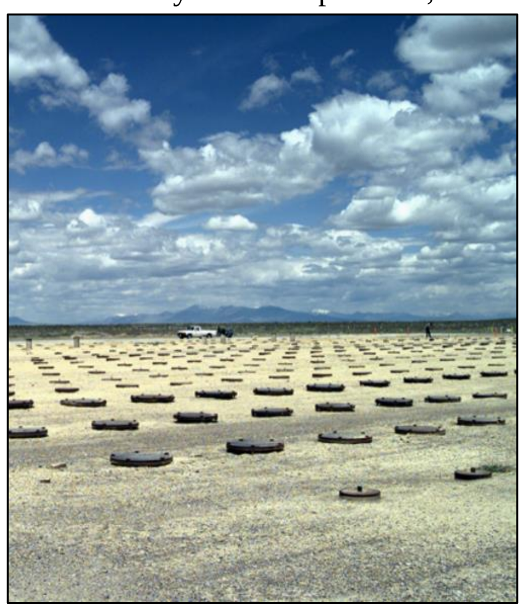


Figure 1: Radioactive Scrap and Waste Facility at Idaho National Laboratory

While extremely versatile, the silo storage system discussed in this paper has been optimized specifically for the storage of DSRS. The silo storage concept is simple and therefore economical to install and operate. The safety functions are passive and thus inherently safe. The design provides a high degree of safety to operating personnel, the public, and the environment. Silo storage is flexible and can be incorporated into a wide variety of environments.

Background and Objective

Throughout the world millions of radiological sources are used for a wide variety of peaceful and productive purposes. Some of these include cancer treatments, sterilization of blood and food, oil exploration, remote electricity generation, industrial radiography, instrument calibration, and scientific research. Radioactive sources vary in physical size, the radiation they emit, and type and amount of shielding required. Some are found inside portable instruments, such as gauges for taking measurements, while others are found inside fixed pieces of equipment, such as a radiotherapy machine for cancer treatment. These sources typically consist of radionuclides contained within a stable matrix and/or a robust capsule or housing. As long as the sources remain properly contained, shielded, and controlled, these radioactive sources and associated devices present no significant health or security risk.

The quantity of radioactive sources, their range of hazards, and the various levels of control from country to country make the task of effectively evaluating and safeguarding these sources a challenging effort. All radioactive sources have a finite useful life and, at some point, are no longer suited for their intended purpose. When this occurs, the preferred path is to recycle them if possible, or if not practical, to secure them in safe storage until they can be recycled or safely disposed. While many “disused” sources could be recycled or disposed of by manufacturers, a large percentage have accumulated at or near their point of use due to the cost and administrative burden associated with proper disposition. It is often easier to keep the source than to provide the resources to process and securely disposition them. This behavior provides a path for loss or an increased opportunity for theft of the source(s) if not safely and securely stored, which is the topic of this paper.

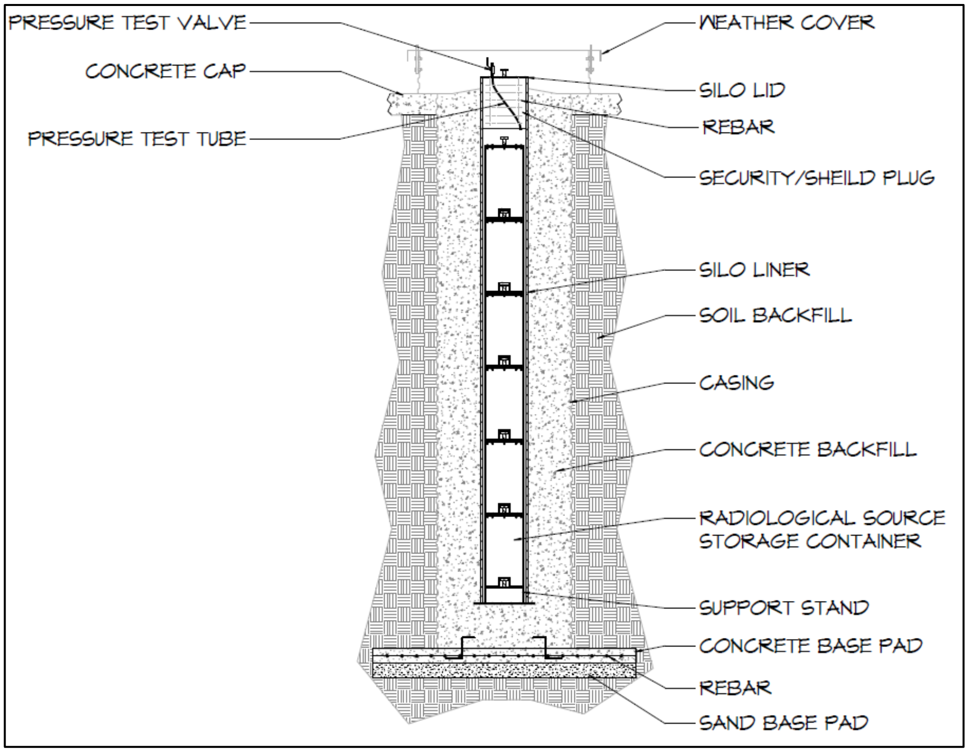
The sponsor for this work is the National Nuclear Security Administration’s (NNSA) Office of Radiological Security (ORS). ORS was established to enhance global security by preventing high activity radioactive materials from being used in acts of terrorism. An important objective as part of this mission is to identify and meet global technology needs to reduce the risk of DSRS to national security. To meet that need internationally, ORS is developing and evaluating mobile and deployable tools as part of a DSRS cradle-to-grave management toolbox from which our foreign partners can choose, enabling them to safely and securely manage their DSRS.

A common and significant difficulty for countries around the world is the safe and secure interim storage of DSRS pending final disposal. ORS is developing the S3 which is an end-of-life management option designed as a regional centralized storage facility.

Design Description Overview

INL has developed a design description which provides supporting documentation for a generic silo conceptual design for the purpose of improving safety and security for radiological sources stored throughout the world. This conceptual design is generic in that the overall silo concept and materials used are constant, but the size of the silo liners, canisters, and the silo field are allowed to change based on the users’ needs. A silo storage field could have anywhere from 3 silos to over a thousand—

the RSWF at INL has 1,350 silos. Additional silos can be added to the silo storage field as needed based on the influx of DSRS for storage. The RSWF at INL has liners that range from 10” to 60” diameter. The length (or depth) of the silos could be as shallow as 6’ or as deep as 25’. Silo storage is very flexible by nature and can be easily customized to meet the user facility needs.



The major components included in this generic silo design plan include the silo liners, lid-shield plug assembly, support ring, concrete backfill, weather cover, and the standardized canisters that will contain the source. (See Figure 2) The silo is constructed vertically by excavating either a rectangular area or trench using standard excavation equipment. Alternatively, auguring is also an option. After soil leveling, concrete forms are constructed, and a rebar reinforced concrete pad is poured for each silo. The outer culvert or pipe casing, used as a concrete form, is placed on the cured concrete pad. The silo liner is placed into the center of the outer pipe and held in place. Concrete is then poured into the annular area between the pipes. The silo protrudes above the soil surface by several inches for canister loading and to seal using the lid-shield plug assembly. A concrete drainage apron is poured around the outer culvert or pipe casing and a weather cover is placed over the top.

Design Features

<u>Radiation Shielding and Decay Heat Removal:</u> Radioactive materials produce both a radiation field and heat from radioactive decay. For that reason, the storage of radioactive materials requires shielding to protect workers from the radiation as well as heat removal to prevent overheating of the housing and engineered structure storing the radioactive materials. While mechanical systems can be used for these functions, there is the potential for failure. However, for silo storage the soil provides the primary shielding while also providing a passive heat sink for the decay heat that is not dependent on equipment or an electrical power supply.

Inherent Safety: Below ground design is less susceptible to accidental impacts or sabotage. Many of the natural disasters that can occur do not impact a silo storage field. Wind based events (hurricane, typhoon, tornado) would have little to no impact to a silo storage field. Earthquakes will sometimes partially or completely unseat a buried item which will be unearthed due to the soil vibration. This concern is eliminated due to the concrete base structure and the oversized silo liner baseplate which are engineered for this purpose. The INL has encountered earthquakes over the years and the silo liners have remained in their buried configuration as designed. Similarly, flooding would be unlikely to have either short-term or long-term impacts on the silo system performance and the DSRS would remain secure and isolated from the environment.

Corrosion Protection: To safely contain radioactive contamination, a minimum of two confinement boundaries are necessary. For the S3, the primary confinement boundary is the canister, and the secondary confinement boundary is the silo liner. Intact DSRS themselves typically provide another level of confinement from their sealed housing; while newer sources may be double contained, older sources are typically single contained. At the S3 user facility's discretion, DSRS that are suspect or actively compromised can be overpacked into a stainless-steel capsule prior to being placed into the canister to provide three levels of confinement for DSRS if preferred.

The primary technical challenge in vertical dry silo storage is the protection of the silo liner from corrosion attack. Corrosion can be described as the destruction or deterioration of a material due to an electrochemical interaction with its environment through the formation of corrosion cells with subsequent ion movement. An engineered cathodic protection system is needed to mitigate corrosion. The four options for S3 corrosion protection are: 1) An active impressed current system; 2) A passive galvanic system with a separate anode connected to the liner by a cable; 3) A passive galvanic system with the anode applied directly to the liner surface combined with passivation of the environment; and 4) A seal coating to isolate the material from the environment.

Each of these four corrosion protection approaches have their own advantages and disadvantages. However, due to the need for a robust and reliable corrosion protection system for use in locations around the globe including in remote areas, INL has selected the third option and developed a passive corrosion protection system with passivation for this optimized S3 for DSRS storage. This S3 passive corrosion protection system is comprised of five components. Listing the five components from the inside out—first are the carbon steel canisters in which the DSRS are loaded; second is the carbon steel silo liner; third is the concrete surrounding the silo liner which passivates soil contaminants by creating a basic (pH ~ 10-12) environment to reduce corrosion; fourth is the culvert or pipe which is used as the outside concrete form; and fifth is the galvanization of the culvert or pipe which is a sacrificial anode and will protect the carbon steel from corrosion.

There are many concrete mix designs and additives to consider during design depending on the local environmental conditions which could also aid in slowing corrosion. After reviewing canister and silo liner material options, the best liner material is carbon steel due to its combination of low cost and worldwide availability. Typically, carbon steel is attacked by general surface corrosion as opposed to pitting corrosion for stainless steel in some soil environments which could compromise containment.

<u>Silo Liner Integrity – Quality Assurance:</u> A quick connect valve is designed into the top of the silo shield plug lid. The purpose of this port is to allow the user facility to positively pressurize (~10 to 25 psi) the silo liner after loading is complete and the shield plug lid is seal welded onto the silo. For nuclear applications, we usually think of negative pressurization to control contamination leakage, but a corrosion attack would most likely occur from outside the silo liner, so a slight positive pressure is preferred. If the silo liner is placed at a negative pressure and the silo is compromised, a negative pressure would tend to draw water and soil particulate/contaminants into the silo which could then increase the rate of canister corrosion. With a safe and low positive pressure, the user facility personnel can readily use a pressure gage to confirm that the silo liner is intact by the simple fact that it is retaining the positive pressure. If for example, a silo liner loses its pressure any time after installation, it has failed, and the canisters can then simply be moved to a spare silo which are installed for this purpose if a repository is not yet ready for DSRS disposal. Annual pressure checks are deemed sufficient, but the frequency of pressure checks would be determined by the user facility and approved by the local regulatory authority.

This simple, safe, and inexpensive approach to ensuring silo liner integrity is based on S3 being a storage facility rather than an operating facility. If the silos were to be repeatedly opened so that the canisters could be manually inspected, radiation exposure would increase for the workers, physical security would be reduced, and the facility operating cost would increase. To avoid these negative ramifications, this simple pressure test approach is recommended to maintain storage facility functionality.

<u>Physical Protection:</u> While the underground storage of DSRS provides some inherent security, the physical protection of DSRS storage facilities is very important. It is recommended that a new S3 be installed within the security zone of an existing nuclear (e.g., research reactor, nuclear power plant, etc.), government, military, or industrial complex. If not, a physical protection system would need to be provided for this or any DSRS storage facility.

Design Documentation Available

The intent of this effort was not for INL to follow a rigorous design process to develop a facility design ready for construction at a specific site. The intent of this effort was to provide an optimized but generic S3 design package to support collaborators who are interested in implementing S3 for their DSRS storage. Consequently, this conceptual design does not begin from a rigorous set of facility-specific design criteria and assumptions. Instead, it focuses on a high-level understanding of DSRS storage goals and objectives--and seeks to apply INL expertise in suggesting effective paths for achieving them while remaining consistent with applicable IAEA standards and guidelines.

The local user facility staff has the latitude to use the S3 conceptual design package as is or to modify it to meet unique or specific needs and objectives. Because INL has the experience of using silo storage and designing various versions of silo storage, that expertise is available to provide design insights and guidance to help ensure sound technical decisions for effective utilization of this technology.

Based on this approach, INL developed a generic design package using International Atomic Energy Agency (IAEA) guides and standards comprised of the following:

- Silo Storage System Design Description
- Environmental Impact Assessment
- Source Acceptance Criteria
- Safety Design Report

The System Design Description (SDD) includes a set of conceptual fabrication drawings for the silo liners, lid-shield plug assembly, support ring, weather cover, and the standardized canisters. The appendices include a comprehensive set of design decision trees to assist the user in making the needed final design decisions for any unique situations that deviate from the generic design.

The generic Environmental Impact Assessment (EIA) was conducted to document the minimal environmental impact of construction and operation of a standard silo storage facility. The EIA also identifies the environmental conditions to be evaluated when determining the location for the storage facility. Again, because of the generic nature of this design, it can be adapted to fit a variety of site-specific conditions.

The Source Acceptance Criteria (SAC) was developed using generic assumptions and criteria and is designed to be adjusted to meet the specific criteria of the country building it. The facility is designed such that it can accept most radiological sources while keeping costs low by not overdesigning to accommodate the few outliers.

The Safety Design Report (SDR) considered all possible accident scenarios and determined their likelihood and consequence level. Based on the likelihood and risk associated with a specific accident, safety systems, structures, and components (SSCs) were identified. Safety-class SSCs are those necessary to prevent or mitigate public exposures that could exceed the evaluation guidelines (EGs) for offsite dose values. No safety-class SSCs were identified for this storage facility based on the definitions for the EGs and the results of the hazard and accident analyses that was conducted. Safety-significant SSCs are those necessary to prevent or mitigate onsite exposure to workers that could exceed EGs.

This generic design package is freely available to countries and facilities interested in collaboration on the implementation of S3 for the storage of their DSRS.

S3 Demonstration

With the intent that S3 could be deployed wherever needed worldwide, an important criterion used for the development of S3 was to utilize only basic and standard fabrication and construction techniques and practices that are used worldwide. To ensure this criterion was met, INL has been working with a foreign collaborator to demonstrate the fabrication and construction of a silo storage facility. The final S3 design, component (canisters, shield plug-lid assemblies, etc.) fabrication, construction, and regulatory commissioning for operational start have all been successfully completed and the facility is ready for operational loading of DSRS.

The five steps that were followed for the demonstration are expected to be standard for future work and consist of the following:

- Step 1: Decision to proceed and site selection
- Step 2: Specific design to meet user needs
- Step 3: Fabrication/construction of S3
- Step 4: Facility commissioning
- Step 5: DSRS packaging and silo loading

Summary and Collaboration

The purpose of this effort was to develop a cost-effective method for DSRS storage that could be used in countries around the world. The conceptual design is a generic, standard design that can be adapted to different locations and needs. The main drivers for this generic design were cost effectiveness and simplicity of construction. The optimized S3 has been demonstrated at a collaborating facility.

This optimized S3 design provides the following features:

- Safe and secure storage of disused radiological sources
- Based on proven technology with decades of reliable performance
- Over fifty-year storage life with minimal to no maintenance
- Flexible design suitable for a variety of locations
- Fully scalable number of silos in storage field
- Cost efficient storage of nuclear materials
- Common materials available around the world
- Flexible design suitable for a variety of silo sizes
- Common construction techniques

If you have any questions or are interested in collaborating on a Silo Storage System to store DSRS, please contact Eric Howden (eric.howden@inl.gov).